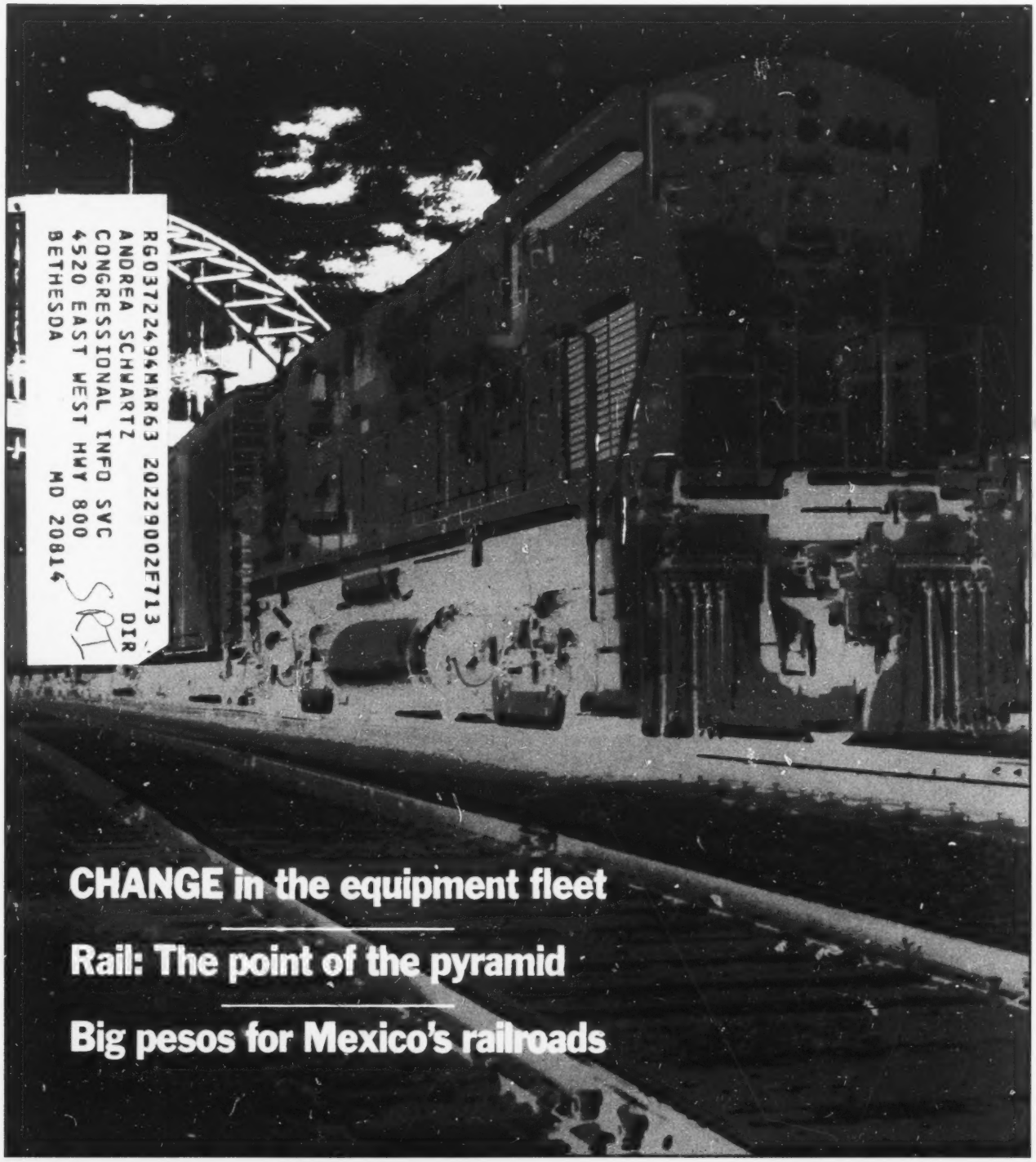
Light rail lights up the West

September 1984

RAILWAY AGE

...for the new age of railways



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CHANGE in the equipment fleet

Rail: The point of the pyramid

Big pesos for Mexico's railroads

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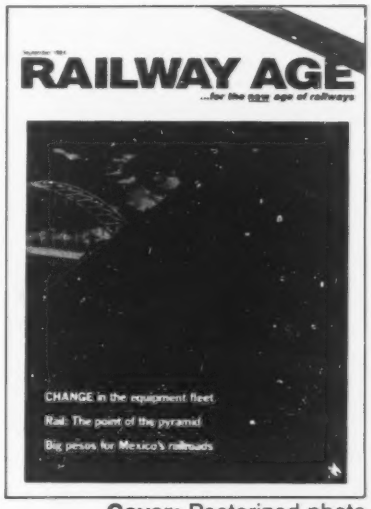
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Cover: Posterized photo by Bruce Harmon of FMC.

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Inside

RAILEXPO: A show of confidence

LUTHER S. MILLER

RAILEXPO '84 will not be the biggest railroad show Chicago has ever seen. The all-time champion of such displays of railroad muscle and technological ingenuity was the American Railway Progress Exposition of 1963. In the autumn of that year, an astounding 40,000 people (and that was only the official registration) trooped past the exhibits of more than 350 vendors at McCormick Place and (if they found the time) attended the sessions of 24 separate railroad organizations that were meeting concurrently in Chicago.

But if RAILEXPO '84 won't be the biggest of them all, it may well be the bravest—and, qualitatively, perhaps the best.

The bravest—because the 150-odd exhibitors who have booked space at this first Railway Supply Association show since 1979 have not, for the most part, experienced the great comeback from the Great Recession that their railroad customers have experienced; their participation is more an act of faith than evidence of present prosperity.

The best—because the equipment to be shown at RAILEXPO '84 has been custom-crafted for the kind of high-productivity railroading that was scarcely dreamed of 20 years ago. Diesel fuel no longer costs nine cents a gallon—and the fuel-efficient, microprocessor-controlled locomotives that EMD and GE are showing this year reflect that sobering fact. In freight-car design, such considerations as weight and wind drag have become enormously important; the response of carbuilders and component suppliers to these railroad concerns will be evident in the new generation of equipment on display at RAILEXPO.

RAILEXPO participants will be demonstrating not only their products and their services, but also their support of—and confidence in—the future of railroading.

Chicago, then and now

In 1963, James M. Symes stepped down as chairman of the Pennsylvania Railroad with the pronouncement that a new era was at hand: "What we have so long advocated had to come along. Mergers, elimination of featherbedding, tax relief, more freedom in meeting price competition....We're making real progress now." His optimism, though premature, was justified.

If there are fewer railroaders at Chicago this year than in '63, they will be smarter—because they have had to learn to be. If there is less equipment, it will be better—because it has to be. And if the optimism is more restrained, it will be more solidly based—because most of those things Jim Symes talked about have at last come to pass.

Market Outlook

Equipment

CN Rail: Ordered 101 track motor cars valued at more than $1 million from Beaver Car Canada, Fairmont Railway Motors, and the Railcar Division of GSP Management.

Kansas City Southern: Ordered 110 100-ton coal cars from Thrall for delivery in this year's third and fourth quarters.

Facilities

BRAE Corp.: Will begin production this month at a new trailer manufacturing facility at Stoughton, Wis. With completion of the new plant, BRAE's trailer production capacity will rise from 2,000 to 6,000 units per year.

Greater Cleveland Regional Transit Authority: Will use part of a $30.4-million UMTA grant to upgrade the heavy rail line between Union Terminal and Hopkins International Airport.

New York MTA: Is soliciting bids for construction, engineering, and major procurement contracts valued at approximately $1 billion, according to the July-December 1984 edition of "An Eye on the Future," which MTA publishes periodically in an effort to attract a wide spectrum of bidders. Now in the third year of an $8.5-billion capital improvement program involving the New York City Transit Authority, Long Island Rail Road, and Metro-North Commuter Railroad, MTA has so far obligated approximately $4 billion.

SAB Harmon Industries Inc.: Has received orders from Chessie System for over $2 million worth of automatic train control equipment; from CN Rail for over $500,000 for 60 sets of motion-sensing and constant warning time devices; from BN and Chessie for hotbox detector equipment worth over $2.6 million; and from Chessie and SP for talking hotbox detector equipment worth over $2 million.

Freight cars

	DELIVERED				
	July		June	Seven months	
	1984	1983	1984	1984	1983
Built new by carbuilders	1,327	260	1,771	6,315	2,364
Built new in RR shops	0	0	0	0	200
Built new—total	1,327	260	1,771	6,315	2,564
Rebuilt	0	29	0	0	29
TOTAL DELIVERED	**1,327**	**289**	**1,771**	**6,315**	**2,593**

	ORDERED				
To be built new by carbuilders	607	934	2,744	10,796	3,500
To be built new in RR shops	0	0	250	250	3
To be built new—total	607	934	2,994	11,046	3,503
To be rebuilt	0	0	0	0	100
TOTAL ORDERED	**607**	**934**	**2,994**	**11,046**	**3,603**

	ON ORDER AND UNDELIVERED				
	Aug. 1		July 1	Average Backlog	
	1984	1983	1984	1984	1983
To be built new by carbuilders	6,571	3,894	7,017	6,454	4,232
To be built new in RR shops	250	3	250	71	39
To be built new—total	6,821	3,897	7,267	6,525	4,271
To be rebuilt	0	71	0	0	39
TOTAL ON ORDER	***6,821**	**3,968**	**7,267**	**6,525**	**4,310**

*Increase in Aug. 1, 1984, backlog due to revision in tank car estimates.

Locomotives (new and rebuilt)

DELIVERED	1984	1983
July	93	11
June	60	13
May	16	22
Seven months	191	125

BACKLOG	1984	1983
August 1	159	167
July 1	202	167
June 1	229	127
Average	157	110

Source: Transportation Div., AAR

Estimated ownership—all revenue freight cars

July 1, 1984 vs July 1, 1983

		Box	Covered Hoppers	Gondola	Hopper	Flat	Refg.	All Others	TOTAL
Class I RRs	1984	258,643	161,421	125,860	275,259	84,642	51,654	21,341	978,640
	1983	279,034	164,009	130,271	288,473	84,509	55,043	22,599	1,023,938
Class II & S&T Cos.*	1984	48,343	9,933	10,136	11,976	4,715	3,244	3,390	91,737
	1983	50,618	9,581	10,727	11,178	5,100	3,371	3,008	93,583
Railbox-Railgon	1984	15,074		3,998					19,072
	1983	15,097		3,998					19,095
RRO&C** Refgs.	1984						5,846		5,846
	1983						5,004		5,004
Private	1984	545	125,787	28,457	22,209	53,605	1,179	183,231	415,013
	1983	444	128,344	27,776	21,335	53,822	2,331	184,945	418,997
GRAND TOTAL	1984	322,425	297,141	168,451	309,444	142,962	61,923	207,962	1,510,308
	1983	345,193	301,934	172,772	320,986	143,431	65,749	210,552	1,560,617

*Class II railroads and switching terminal companies.
**Railroad owned and controlled refrigerator car lines.
Source: Transportation Div., AAR.

Market Indicators

NCA coal forecast

Although demand for U.S. coal is increasing at a slower rate than was predicted two years ago, a revised National Coal Association forecast indicates continued growth in all markets. The biggest increase is expected to occur in coal exports, which NCA predicts will grow by 72.7% during the next ten years. Consumption by general industry, residential and commercial users is expected to increase 68.4% between now and 1995. And consumption by utilities—the biggest users of coal—is predicted to grow by 24.8%, although NCA expects their share of total consumption to drop from 77% to 72%.

For the short term, however, there remains the threat of a coal strike. The United Mine Workers contract expires Sept. 30.

U.S. Coal Production and Consumption

(excluding anthracite, in millions of tons)

	1995*	1984*	1983	1982	1980	1978	1976	1974
U.S. coal Production	1,121	853	781	834	824	665	679	603
U.S. coal Consumption by:								
Utilities	811	650	624	593	568	480	447	390
Steelmakers	51	46	37	41	67	71	84	90
General industry/ Residential & Commercial	128	76	73	71	64	70	68	73
U.S. coal exports	133	77	77	105	90	40	59	60
Synthetic fuels	5	—	—	—	—	—	—	—
Total demand	**1,128**	**849**	**811**	**810**	**789**	**621**	**658**	**613**

*Estimated

Source: National Coal Association

Revenue freight carloadings

Commodity	Aug. 11 week	% change from 1983	Aug. 4 week	% change from 1983	July 28 week	% change from 1983	July 21 week	% change from 1983
Grain	27,378	(7.0)	26,921	(4.5)	25,104	(10.6)	28,194	(5.3)
Other farm products	2,540	(32.0)	2,549	(29.7)	2,943	(30.4)	3,504	(17.5)
Metallic ores	17,440	(4.4)	19,079	21.9	19,666	(3.2)	18,070	(13.5)
Coal	130,809	17.1	129,735	25.8	129,605	20.4	125,767	28.0
Crushed stone, gravel and sand	12,805	12.6	12,612	11.0	13,011	15.4	12,786	12.3
Nonmetallic minerals	12,468	19.9	12,783	4.9	12,891	6.0	11,827	(4.4)
Grain mill products	10,242	(9.9)	10,392	(9.0)	9,805	(13.3)	9,714	(14.2)
Food and kindred products	10,373	(10.3)	10,924	(5.3)	10,606	(9.3)	10,818	(3.6)
Primary forest products	13,480	(5.0)	12,859	(9.4)	14,094	(4.0)	13,460	(10.3)
Lumber and wood products (except furniture)	7,035	2.5	7,312	3.2	7,291	(9.3)	7,002	(1.2)
Pulp, paper and allied products	14,466	(2.2)	14,938	3.0	14,646	(4.0)	14,396	(1.2)
Chemicals and allied products	23,480	2.8	23,732	4.7	23,742	4.3	23,269	14.5
Petroleum products	4,647	(4.0)	4,637	(2.1)	4,884	5.4	4,818	9.8
Stone, clay and glass products	10,884	(4.4)	11,272	3.4	11,222	(1.2)	11,183	1.2
Coke	5,173	(3.4)	5,185	(0.2)	4,752	(8.8)	5,118	(7.3)
Metals and products	7,917	(2.7)	9,018	29.3	9,399	12.2	8,998	15.2
Motor vehicles and equipment	16,488	22.2	16,347	19.5	17,747	18.6	18,286	23.9
Waste and scrap materials	8,604	9.0	8,663	14.1	8,877	11.1	8,929	7.8
Forwarder and shipper assn. traffic	7,237	(9.5)	7,874	1.6	7,354	(10.2)	6,915	(11.6)
All other carloads	58,264	13.5	58,425	14.5	58,495	10.9	57,627	11.7
LCL traffic	122	(59.2)	126	(53.8)	133	(49.4)	134	(37.7)
Total Cars Loaded	**401,852**	**6.5**	**405,383**	**11.3**	**406,267**	**6.6**	**400,815**	**8.9**

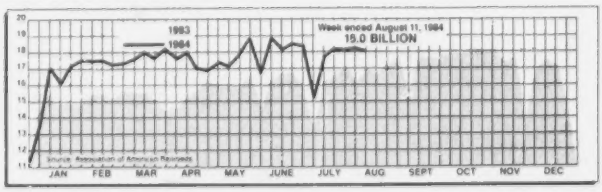
Estimated revenue ton-miles (billions)	1984	1983	% change from 1983
32 weeks	568.4	494.2	15.0

Piggyback loadings

Week ended	Cars loaded 1984	% increase from 1983	Trailers/ containers 1984	% increase from 1983
July 14	49,405	12.2	84,076	9.6
July 21	50,748	11.1	87,668	10.2
July 28	51,928	9.6	89,253	9.6
August 4	51,916	13.6	88,640	11.1
Cumulative total,				
31 weeks	1,562,995	16.4	2,701,519	16.5

Rail freight traffic trends

Billion ton miles (Estimated)



Rail: The point of the pyramid

The search continues for the best combination of the many possible improvements that will weed out flaws and be most effective in enhancing the steel rail's reliability and life.

By JOHN ARMSTRONG, Associate Editor

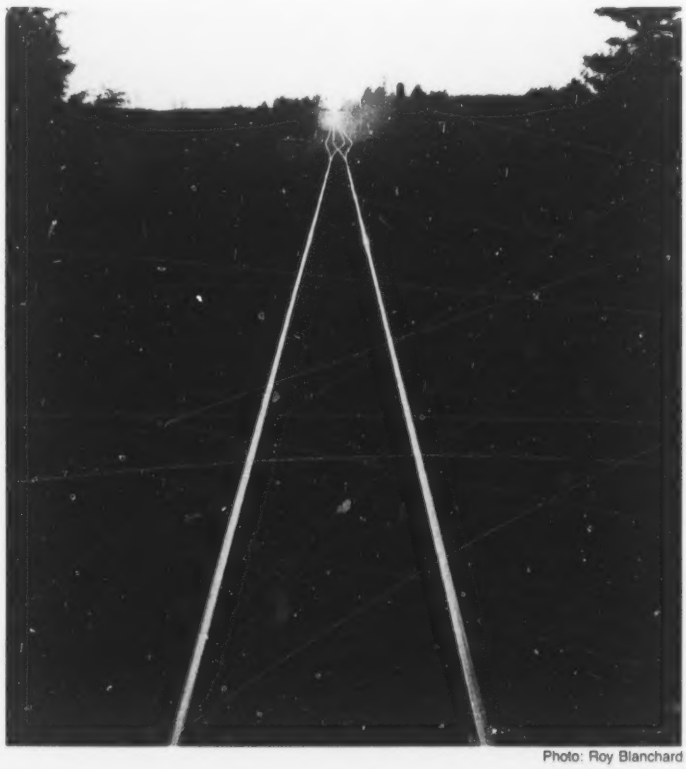


Photo: Roy Blanchard

At the tip of the pyramid of tie plate, crosstie, ballast and sub-ballast that must spread out today's typical North American 33,000-pound wheel load to an intensity the roadbed can sustain is the rail itself—or, more pointedly, that "contact patch" of about 1/6th of a square inch between wheel and railhead. Along with the vertical guidance—basically from flanges rubbing on the rail—which makes *trains* possible, the load capacity and low friction attained with such intense loading between hard, elastic elements is responsible for the efficiency and, indeed, the very existence of the whole industry.

Not only must the steel withstand this rolling load, along with a spectrum of dynamic effects ranging up to flat-wheel impacts which can be as high as six times the static load; it must also survive such treatment year after year. Uniquely among industrial technologies, rail transportation routinely strengthens the character of one of its largest capital assets by loading it *beyond* its yield point.

The reason for doing this, of course, is that it pays—not without controversy, and not without abundant problems which have been kept in bounds only with a century's worth of know-how (empirically- and scientifically-generated) brought to bear through massive investment in production, quality control, handling and maintenance facilities.

• **Even the "plain" is special.** As anyone who has tried to hacksaw through an old piece of rail to create a set of fireplace andirons is well aware, rail steel is *hard*. More than 90% of the approximately 34 million tons of steel in place in the 160,000 first-track miles making up the U.S. line-haul network is "plain carbon" by designation. In composition it actually bears little resemblance to the carbon steel making up the vast bulk of the bridges, building skeletons, concrete reinforcing bars, machinery, "tin" cans, household appliances and automobiles (and freight cars, too) on which so much of today's quality of life hinges.

The 0.70% to 0.80% carbon content typical of rail of main-line weight puts it within the classification of *hard* steels, usable only when temperature-time history in manufacture has been precisely controlled to result in a microstructure with the right combination of hardness and toughness for the intended use. Only tool and spring steels are of higher carbon content; tonnage production of these typically is only about a tenth that of rail.

Also found essential from the earliest days of large-scale steelmaking (by observing that the product made from iron lacking these elements consistently resembled Swiss cheese as a result of violent evolution of oxygen during the solidification process) were manganese and silicon; Mn and Si contents up to about 1.0% and 0.3% respectively are typical of "plain" carbon rail. Also crucial to reliable and workable steel are respective phosphorus and sulfur contents below 0.035% and 0.04%.

Though something as long established as the iron-carbon phase diagram may tend to be considered low-tech these days, rather basic AAR-sponsored metallographic studies at Carnegie-Mellon since the advent of scanning electron microscopy have provided some new and useful answers to old questions. To oversimplify what is still a rather complex situation, the desired microstructure for rail is *pearlite*, grains made up of minute layers of extremely soft pure iron (ferrite) and extremely hard iron carbide (cementite—Fe_3C) with an overall composition equal to 0.83% C and pearly in appearance. The finer the layering in the pearlite, the harder and stronger, to a limit of perhaps 450 Brinell and 225,000 psi; the finer-grained the steel, the tougher it is at any given level of hardness.

So, all the mill has to do is to produce rail-shaped pieces of steel with a high enough proportion of such microstructure—at least in the critical areas—and all the railroad has to do is join them into tracks and maintain the rail's integrity throughout a lifetime which may extend beyond a half-century.

• **It's not all metal.** Steelmaking by any process involves controlling a melt which at the white heat of 2,800 degrees Fahrenheit avidly interacts with the atmosphere and with every container it contacts. Good steelmaking practice slags off many of the undesirable constituents, combines them into inclusions such as calcium manganese silicates whose

nature is not incompatible with steel toughness, or induces them to collect where they can be cropped off after solidification has largely, for good or ill, determined the heat's chemistry. Inclusions must be controlled, but they can not be eliminated entirely.

Starting with ingot or bloom, the steel must complete a dozen or so passes through the rolls, including hot-sawing into individual-rail segments and cambering so it will end up straight when cool, within the five minutes or so within which it remains within the 2,300- to 1,800-degree upper forging temperature range. Otherwise it may end up full of residual stresses in return for giving the rolling mill a hard time with its excessive stiffness.

The structure and hardness of the steel is determined by its cooling rate on the hot beds as it drops below the 1,500-degree point where recrystallization from the austenite phase (stable at rolling temperatures) to pearlite takes place. Air cooling of carbon rail steel results in the standard hardness of about 255 Brinell with good toughness—as verified for each heat or ingot by chemical analysis, drop testing of a section of rail, and examination of the fractured surface in a notch-and-break test, per AREA specifications of long standing.

Since the 1930s it has been recognized that one melt constituent intolerably detrimental to rail integrity is hydrogen; hydrogen flakes segregating in the rail after rolling lead to internal "shatter cracks" which may grow in service into transverse fissures. Twenty-four hours in cooling boxes starting at no lower than 775 degrees Fahrenheit gives the hydrogen time to diffuse out from the rail, virtually eliminating this particular problem at the cost of a major interruption to the production process.

Numerous other sources of flaws have been tracked down and reduced in one way or another—for example, the central pipe at the top of the ingot likely to show up as a longitudinal split in the web can be properly minimized by hot-topping and cropping or going to continuous casting. The more homeogeneous and generally "clean" the steel, the fewer problems (mostly those requiring premature replacement, but some showing up in the accident statistics—see box) in the track over the rail's lifetime.

• **Clean, straight, weldable.** So, one of the things the railroad chief engineer wants is *clean* rail. How do you get cleaner rail? Undoubtedly, the continuous casting process works in that direction by shrouding the steel from the atmosphere during the process, speeding up solidification so there is less opportunity for chemical segregation, and providing a smoother surface for the steel than the typical ingot mold. Inert-gas stirring prior to casting helps homogenize the constituents, float out slag, and control deoxidation. Small doses of powerful deoxidizers such as aluminum are preferred by some steelmakers but shunned by others who feel that the geometry and hardness of the resulting inclusion compounds may result in more rather than fewer effective stress-raisers in the finished rail. The major complication of going to one of the various methods for pouring steel in a vacuum finds favor with all three railmakers in Germany, where the resulting virtual elimination of hydrogen is considered sufficient to allow dispensing with controlled-cooling.

Even with FAST, it can take a long time to see for sure which combinations of the many possible improvements are most effective in enhancing rail reliability and life.

In recent years ultrasonic inspection has become a powerful tool for weeding out specific flaws, in the mill as well as in the welding plant and out on the road. Improving the acoustic coupling, number and look-angle of probes—and automating the process to make inspection of head, web and base of every rail affordable—has been a continuing matter now approaching universality. Suspect areas paint-marked and computer-recorded by the automatic system can then be examined in detail with hand-held probes to determine the fate of any rail in question.

Since it's difficult enough to keep track line and surface up to snuff after the rail is in place, our chief engineer would also like the rail to start out *straight*. Automatic roller-straightening is a lot less labor-intensive and dependent upon operator skill than the time-honored practice of using three-point pressure in a gag-press under a trained eye to remove kinks individually and personally; it can be a sufficiently drastic process, particularly with harder rail, to raise renewed questions regarding the residual-stress state of the rail. Press straightening leaves stressed areas, too, but affecting only short segments of the rail.

Traditionally, the length-of-rail standard in North America practice grew in synch with the length of freight cars readily available to transport it, at least until after the 1920s when it stayed stuck at 39 feet as cars continued to lengthen beyond 40½ feet. Now that there are surplus 85-foot flats and most rail is going to be welded and transported as 1,440-foot cwr strings anyway, the engineer is happier with half as many pieces and half as many welds, so 78-foot rail has a selling point.

Rail steel must now also be *weldable*, both in plant and under the less controllable situations in the field, and preferably without requiring special pre- and post-heating cycles to avoid the development of brittle martensitic components in the microstructure of the heat-affected zones. This requirement has tended to restrict the percentage of manganese usable in developing steels somewhat harder than standard.

• **Harder, too.** Our engineer would also like his rail to last forever, or at least not wear out so fast on curves that he has a continuous battle with the operating department for track time to transpose and relay it. Here, the extra *hardness* of premium rail comes to the fore. A payoff justifying the difference between $472 a ton for standard and as much as $200 more for something expected to prove more wear resistant may look solid in a paper analysis based on experience elsewhere in the industry; but both engineering officers and managements watching their budgets still seem comfortable only after long experience with test sections on their own properties—a conservatism for which ancient roots exist:

> Unfortunately, a few years since the result of an investigation on the Pennsylvania Railroad into the wearing qualities of steel rails which showed, or seemed to show, that very hard rails did not wear so well as softer and tougher rails, was taken to indicate that softness itself was a desirable quality in a rail; and the painstaking character of the investigation and the reputation of the road having given these conclusions wide dissemination, manufacturers ... took them as a guide, and between 1880 and 1885 produced rails which have worn away very rapidly so that their life has often been only a year or two under very moderate trunk line traffic.
>
> —A.M. Wellington, *Railway Location*, 1887 Ed.

It is by now generally accepted that *harder* rail provides longer life, particularly on curves, to an extent justifying some premium price, and that it can be achieved by various methods as discussed below. Once the determination has been made that what is wanted is cleaner, straighter, harder rail, from whence does this rail come? Over the past 10 years, from overseas.

The steelmaking process, like other capital-intensive, high-tonnage manufacturing, doesn't lend itself to rapid change. Over the 1975-83 period, the proportion of raw carbon and alloy steel produced at the major mills in the United States by the open hearth process has declined from 19.0% to 7.1% while electric steel production has risen from 18.6% to 30.0%, with basic-oxygen steel remaining at 63%. The portion produced by continuous casting has gone from 8.3% to 32.0%. The alloy-steel portion, somewhat surprisingly, declined from 13.1% to 10.8%. Rail steel production throughout the period (Table I) has represented from 0.9% to 1.3% of total domestic raw-steel production.

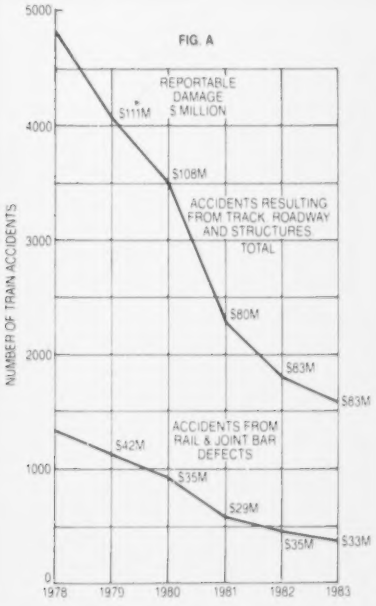
With the inherent edge in rail steel quality resulting from newer production methods and equipment, however, imported steel—much of it premium—took 35.4% of the U.S. rail market in 1982. Last year, in a total market (domestic production plus imports) down from 771,000 tons to 701,000 tons, imports—in both years roughly equally split between Japanese and European sources—declined to 12.7%.

• **A reshaped rail industry.** Rated annual steel mill capacity of the four rail mills in the U.S. at the time of the last A.I.S.I. survey in 1980 was a whopping 3,546,000 tons. That total doesn't necessarily represent the situation, since some other products may be rolled in rail mills; but since the maximum amount

Rail failures: The danger decreases

In the six years since renewed attention to right-of-way maintenance on U.S. railroads started the FRA train-accident category "Defects in Track, Roadbed and Structures" on its current downward trend, the number chalked up against rail and joint bar defects (Fig. A) has decreased by 72%, a bit more than the overall reduction (67%) in track-caused accidents. Reportable costs have also shown a decreasing tendency, irregular and in the face of inflation less striking in degree.

Accidents from rail and joint bar defects are broken down into 19 specific categories plus that old and seemingly irreducible catchall, "other," which currently accounts for about one quarter of the total damage. Some are so rare that further action to get down to zero is hard to visualize; some, such as derailments attributed to excessively worn rail, rarely happen without warning and are more directly chargeable to deficiencies in inspection than to rail quality. Others remain frequent and costly enough to point toward research which should help further reduce the overall cost of transportation by rail.



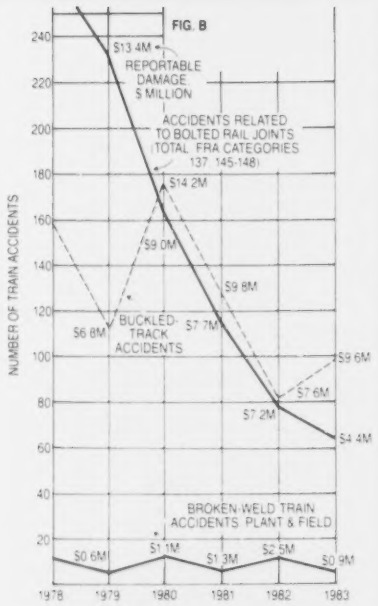
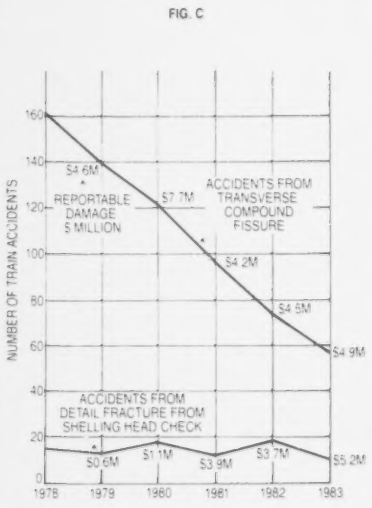


Fig. B aggregates a half-dozen categories associated with rail joints, including head-web separations in the joint region, broken bolts and joint-bar failures. As would be expected during this period when the number of joints is declining as conversions to cwr continue, accident numbers have been cut by 80% and annual costs by $9 million. *Accidents* from failures—"pull-aparts"—associated with the welds, plant and field, that replaced the joints are extremely rare. Pull-aparts do occur, but most are detected, by track circuits or otherwise, or do not result in derailment. Accident reduction is not the primary reason for going to cwr, of course, but even in a bad year the balance in the "rail and joint defects" category has been favorable.

The flip side that must be considered, though it's not exclusively associated with cwr, is *track buckling*. The modulus of expansion of steel being immutable, the problem can't be laid on the metallurgist; as the overlay on Fig. B indicates, results to date appear to justify the search for a track-stress monitor to warn of incipient disaster. Current trends setting rail-equilibrium temperatures nearer to the hot end of climatic extremes appear in line with the relative perils of compression and tension in rails and welds.

Remaining expensive are two defect categories (Fig. C) ultimately resulting in complete rail fracture if not detected in time. Although distinguishing between the two is to some extent a matter of judgment and they may not in all cases be correctly reported, in general "transverse/compound fissures" are those originating at a material defect deep within the rail head. Accidents attributed to them have been steadily declining in number, probably to a considerable extent from final retirement of old, fissure-prone rail antedating controlled cooling. "Detail fractures from shelling/head check," on the other hand, start nearer the surface of the rail (often near the gauge corner) where today's heavy axle loads produce high stresses and fatigue. Some of these as they grow under traffic turn downward where they may end up in sudden transverse rail fracture; their number has not been declining and the resulting accidents can be expensive ones. A major thrust of FRA and AAR rail research is directed at isolating, measuring and controlling factors affecting their growth.



of new rail laid in any one of last 30 years was 1,065,000 tons (in 1979), it's apparent that capacity was not exactly tight.

The ticket for a new rail mill—exclusive of the steelmaking capacity to feed it—is $200 million plus; employment at any plant capable of rolling standard rail in practical quantities, even at today's level of automation, is enough to impact a community heavily. So, you don't stay in or get into the rail business casually. With U.S. Steel's closing of its rail mills at Gary, Ind., and Fairfield, Ala., and its decision to demolish its South Works at Chicago and leave the market rather than add a $225-million rail mill at the site (actions which the State of Illinois is fighting in the courts on the basis of tax-break legislation and pollution-control concessions advanced in prospect of mill construction), there are only three active rail mills in the United States.

In an industry whose overall difficulties as one of the old kids on the block have been well publicized, each active mill has some definite claims to fame; in the aggregate, methods of rail steel manufacture prevalent in the U.S. have undergone a major reshaping in a rather short time:

—CF&I Steel's rail plant at Pueblo, Col. was the first domestic mill to establish a capability for rolling rail in lengths up to 8-

feet, significant in these days when most rail is headed immediately for cwr. Both Denver & Rio Grande Western and Burlington Northern have rail welding plants right in Pueblo. Roller-straightened in both plants since 1979 and automatically scanned ultrasonically since 1982, rail from this Crane Co. subsidiary is available in standard, intermediate-hardness (for improved wear resistance on track of moderate curvature) and its trademarked chromium-molybdenum premium ("Cromorail") grades, all of established seniority. CF&I's decision to shut down its coke plant and blast furnaces last December ended basic steel production in Pueblo, so all rail production now comes from scrap melted and processed in the electric furnace.

—Wheeling-Pittsburgh made use of a Federal loan-guarantee program available at the time in adding a $105-million rail mill to its existing Monessen, Pa., plant. The rail mill went on line in the recession year of 1982—"not exactly the timing we had in mind when construction was started, but it did give us a chance to show what we could do without being under too much pressure." Right from the start, it has produced roller-straightened, ultrasonically-inspected rail in 25-meter or 78-foot lengths from its state-of-the-art five-strand continuous bloom caster. Steel comes from the existing basic-oxygen-process plant. In common with Canadian and European rail mills, Wheeling-Pittsburgh has chosen to make premium-hardness rail by the alloy route (0.6% chromium, 0.2% molybdenum with manganese content reduced to about 0.6% to avoid weld embrittlement).

—Bethlehem Steel's plant at Steelton, Pa., has received an $85-million upgrade, which went into production in January of this year. A Demag continuous caster supplied with inert-gas (argon) -stirred steel from its existing electric melting furnaces turns out three 14.6- × -23.6-inch jumbo blooms to feed its existing rail rolling lines. Remaining unique is Bethlehem's capability (established in the 1940s) for producing fully heat-treated premium-hardness rail, a massive capital improvement which it logically continues to exploit. The carbon-steel rail is now roller-straightened both before and after the quenching and tempering operation.

• Head-hardening lives on. Termination of U.S. Steel rail production represents the end of domestic production of head-hardened premium rail. Railroads which have paid the extra for its Curvmaster to extend rail-renewal periods will find head-hardened carbon rail still available, however, and produced by different techniques as well. Nippon Steel head-hardens carbon rail, after straightening, by induction heating and a process it refers to as "slack quenching."

Nippon KK's recently introduced premium rail is also head-hardened with a controlled compressed-air quench, but after flame heating; a head-hardened *alloy* rail is also offered which the company believes should provide about 20% more wear resistance than its carbon HH rail. Head hardnesses considerably above typical alloy rail figures are cited for both.

Algoma steel, currently producing alloy premium rail, has its research organization working with "a non-traditional, patented heat treating process for producing rail of superior quality." Rail is in field test; though announcement of the new product has not yet been made, comparatively low capital-equipment cost is cited as its advantage over other heat-treating methods.

British Steel is also understood to have resumed work on a residual-heat hardening process.

As appropriate in its coastal Nova Scotia location, Sydney Steel has been an exporter since 1908, experienced in rolling rail, including double-length, to UIC, AREA, AAR or other specifications in favor in any part of the world. Returning to production this month after shutdown for completion of a modernization program totaling $96 million (Canadian) for the integrated steel producing plant as a whole, rail-making improvements include a hot-bed inspection line and added hydraulic press capacity for rail-end straightening if needed to complete the job done by its two-axis roll-straightener (said to be the first put in service in North America).

In addition to standard and high-silicon, Sydney's catalogue includes two premium-hardness alloy-steel rail options—columbium (niobium)-chrome or chrome-moly—of similar properties. It produces either vacuum-degassed or controlled-cooled rail as specified and supplements ultrasonic inspection with magnetic particle inspection to eliminate base seams. Present rail production is from hot-topped ingot steel, although a continuous caster has been in service when production warrants.

It's generally agreed that both hardened carbon and alloy rail of proper formulation and manufacture can be made hard enough to reduce curve wear to a degree worth the premium while remaining tough enough for safety—but that margin has to be watched carefully.

• Focus on fracture. Designing a structure to last forever is essentially a matter of proportioning it so that no frequently-repeated service loads stress the material beyond its fatigue limit. Although scatter in laboratory tests measuring it is a problem, steel (unlike many other materials, notably aluminum alloys) typically *does* have such a limit—a value below which stress cycles repeated to the practical limits of test time and money simply don't generate fatigue failures. If working stresses are above this limit, fatigue cracks will ultimately grow and the structure will have a finite life; whether or not this is acceptable then depends on how long and, particularly, how *predictable* this life is in relation to service life expectations, the price of alternatives, consequences of failure, and other economic and emotional/political factors.

Considered as a bridge distributing wheel loads to the crossties, the size and shape of today's rail sections (as refined over the years to put the metal where it can carry the load without excessive stress concentrations in such critical areas as the head-web fillet) are such that stresses are well below the fatigue limit. In the wheel contact area, however, no practical combination of larger-diameter wheels or reduced axle loading can keep stresses anywhere near the fatigue limit.

Cracks start only where there is tension; both contact stresses and residual stresses at the railhead surface resulting from cold-working by wheel loads are compressive, so fatigue cracks typically start a fraction of an inch below the surface. Eventually some will grow big enough to be potentially dangerous—and also big enough to be found at the next detector-car inspection. When the cost and disruption involved in cutting out and replacing defective sections reaches an uneconomically high level, the rail has "fatigued out" and should be cascaded downward to trackage where tonnage, speed and load conditions predict worthwhile remaining life—or disposed of if the railroad has run out of such opportunities.

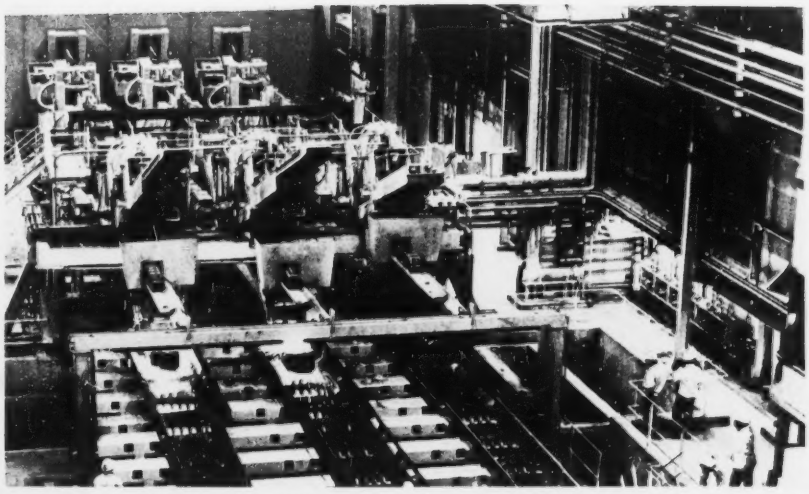
It would be ideal if axle loads, rail lubrication, vehicle dynamics, rail metallurgy and the host of other factors affecting the situation

TABLE 1
NET U.S. STEEL MILL SHIPMENTS
(Thousands of Tons)

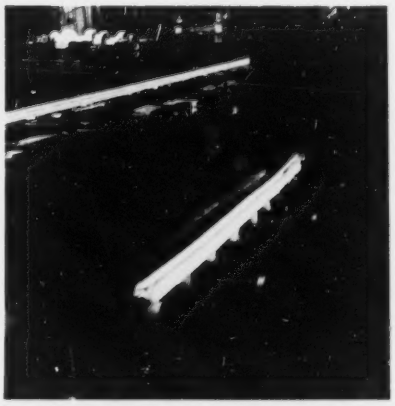
Year	Standard rails	Total steel products	Rail, % of total
1974	924	109,472	0.8
1975	1,179	79,957	1.5
1976	1,303	89,447	1.5
1977	1,109	91,147	1.2
1978	946	97,935	1.0
1979	1,122	100,262	1.1
1980	1,085	83,853	1.3
1981	907	88,450	0.7
1982	498	61,567	0.8
1983	611	67,583	0.9

Source: American Iron and Steel Institute

In common with Canadian and European mills, Wheeling-Pittsburgh's three-year-old mill in Monessen, Pa., produces premium-hardness alloy rail. Pictured is the company's roller straightener and hot saw.



Upgrading of Bethlehem Steel's Steelton, Pa., plant was completed late last year; its most spectacular feature is a continuous caster that creates three 14.6-by-23.6-inch jumbo blooms at one time.



CF&I Steel's plant in Pueblo, Colo., was the first U.S. mill to tool up for 82-foot rail. No longer involved in basic steel production, the plant's rail now comes from scrap melted and processed in electric furnaces.

could be so balanced that rail would reach first-service wear and fatigue limits at the same time. Is this as unlikely as running out of dip and crackers simultaneously at a cocktail party? As of now, for general-service railroading, probably yes—but researchers feel that insights on the interactions of major factors coming together from experience on single-commodity heavy-haul railroads, FAST, railroad test sites and a variety of laboratory studies and analyses will provide increasingly clear guidelines for railroad decision-makers. Some are already in hand:

—Rail lubricant itself does not increase the growth rate of fatigue cracks, though it is true that reducing head wear by lubrication may extend rail life until the fatigue takes over as the governing mechanism.

—The *character* of head wear may be very significant in the initiation of detail fatigues; maintaining railhead contours that reduce contact between the wheel flange fillet and the gauge corner is worthwhile in some cases.

How frequently must rail of a given type under a given density and type of traffic be inspected for defects if sudden rail fracture is to be precluded? Experimentally, the rate of growth of cracks under traffic has been studied in FRA-sponsored tests at FAST by inserting rail sections with service-induced flaws of reasonably well known size, and more work of this type is planned. To the extent that the maximum growth rate of identifiable types and sizes of defects can be established, detector-car scheduling can be more rational. Analytically, AAR Tech Center's Roger Steele expects application of crack-growth math models derived from roller-bearing studies at Northwestern University to help understand how—if not at this stage *when*—cracks parallel to the surface turn in the malignant transverse direction.

• Fracture mechanics. Examining all routes toward the *elimination* of sudden rail failures and the big-ticket accidents they still occasionally cause (see box) also requires continuing examination of what such relatively new disciplines as *fracture mechanics* can contribute toward determining whether or not a particular class of rail defect may suddenly cause a catastrophic failure.

Fracture mechanics, advanced greatly by studies in the aftermath of highly visible ship break-in-two's during and after World War II, has the basic goal of determining the geometric, material, environmental and stress conditions under which a crack suddenly becomes "self-powering" and zippers through a structure at fantastic speed (in steel, about 3,000 feet per second). Oversimplifying a subject which has been developed only with aid of the most advanced experimental and analytical techniques, it has been rather well established that:

—*Fracture toughness* of a given material (as measured in terms of the energy required to break off a cracked specimen) is the important indicator of its ability to resist sudden failure. Fracture toughness typically falls from normal to a value many times lower over a rather narrow "ductile-to-brittle transition" temperature range.

—For any given structure size, geometry, material and stress condition, there is a certain *critical flaw size*. Only when this is exceeded will sudden catastrophic cracking occur.

Structures such as bridges, ships—and freight cars—can avoid unpleasant brittle failures by specifying (and paying for) material whose transition temperature is below the lowest expected in service; low-quality mild steel may have a transition temperature above freezing but modest alloying (nickel) and control of other metallurgical factors can push it below Arctic requirements.

Carbon steels of rail hardness, on the other hand, have transition temperatures in the range of 275 degrees Fahrenheit and so are operating in their "brittle" regime throughout the year. Adequate fracture toughness is thus a must; the standard AREA physical tests do not directly measures this, but it is characteristic of the classes of rail steel whose level of performance has been demonstrated in service over the years and whose heat-to-heat uniformity is verified by the tests.

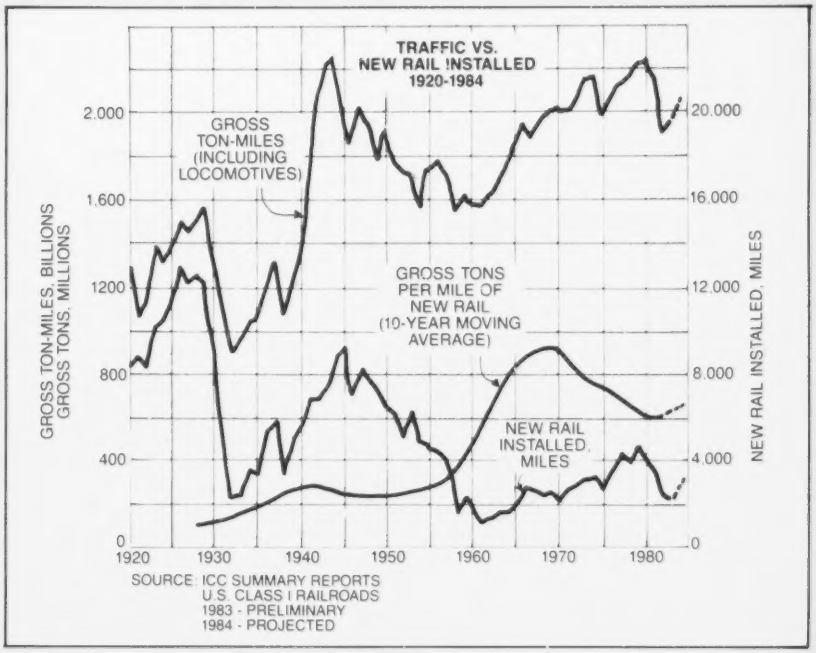
Why do cold snaps in the −30-degree Fahrenheit range result in so many broken

Does rail last like it used to?

Have fatigue and other effects of heavier axle loads proven so damaging to rail life that its tonnage-carrying efficiency is declining despite such favorable factors as elimination of rail-end batter by cwr, increased attention to rail grinding and the general upgrading of maintenance of way in recent years?

The accompanying chart plots the 1920-1984 history of rail life on U.S. railroads in terms of *gross ton miles of traffic per mile of new rail installed*, including locomotives and considering passenger- and freight-train gross tons equivalent in effect on rail life.

Since *overall* track wear in terms of total traffic in gross ton miles is independent of the length of line over which it is spread and new steel is commonly injected into the system when main-line rail has served out its first life whether or not it can be cascaded, the result is generally comparable to the familiar MGT number used in comparing or estimating rail wear and tear on individual track segments. In order to clarify trends, short-term fluctuations in traffic and corresponding curtailments in new-rail programs which faithfully (if sometimes counterproductively) follow them have been smoothed out by plotting the 10-year moving average.



In the absence of a good measure of the *overall* condition of railroad properties for evaluating the effect of extended periods of deferred or augmented maintenance, it may still be too soon to conclude that effects of introduction of the 100-ton car in the 1960s are fully reflected by the moving averages (projected through 1984) presented. Nevertheless, it appears that today's rails are surviving more than *twice* the 250-300 MGT sustained during a similar period of rebuilding in the late 1940s under 50- and 70-ton cars, and at least *five times* that typical of the 1920s when the 40-ton car was most prevalent. It is also apparent from results in the field that the rails of the 1960s could not endure 800+ MGT without serious degradation under the maintenance conditions of the time.

These MGT-based figures also somewhat understate the freight-carrying efficiency of today's system since the ratio of net to gross ton-miles increased more than 20% between 1930 and 1980.

What may such factors as perfected wheel lubrication and harder, tougher rail do to these numbers—and rolling mill tonnage—in the 1990s?

rails? Current belief is that the governing factor is the increase in track stiffness and resulting impact loading from the extremely hard-frozen roadbed: the unattractive palliative remains the same—slow orders until the temperature rises.

• Staying out of the danger zone. So, rail is a critical structure which must work in the brittle range of its material, at stress levels which insure the generation of some internal fatigue cracks in service. If cracks are detected before they reach critical size, the situation is at least stable. Can that situation be retained with harder, more wear-resistant rail?

In the case of some structures such as light weight pressure vessels which are of simple geometry, it has been possible to use ultra high strength materials of low fracture toughness by insuring that under the precisely known conditions of loading, the critical crack dimension is larger than the thickness: A developing crack will reveal itself as a leak before a rupture can occur. Such a hair-raising procedure doesn't fit rail loading, but clues to maintaining a margin of safety abound in a recently-released report of the FRA task force examining last November's shattered-rail derailment of Amtrak Train 21 running on the Missouri Pacific near Marshall, Texas.

What happened was a result of an egregious maintenance situation: The end of a Krupp chrome-vanadium alloy-steel rail, flame-cut in the field and projecting 1/16 inch above a carbon-steel rail to which it was bolted in emergency repair of a pull-apart, survived passage of a freight train at 52 mph. But it shattered over 33 feet into more than 90 separate fragments when struck by a train traveling somewhat below full 79-mph track speed. Calculated impact load was 240,000 pounds with a duration of 0.4 millisecond. Material test results conducted to date indicate that fracture toughness of this rail (representative of about 340 track miles of generally similar composition currently in service in the U.S.) is approximately half that of standard carbon steel and more typical domestic chrome-molybdenum alloy rails.

Is such alloy steel usable? The FRA task force noted that a more typical 10-mph slow order over such a repair would still provide ample margin against such a failure mode and recommended long-term research in such areas as residual rail stress and fracture toughness. It concluded that "there are no inherent reasons why acceptable combinations of manufacturing, operating, and maintenance practices cannot result in the safe use of alloy rail." It can be done, but it will take some doing.

• A "barrel of youth" for rail? Since sound, reliable welds and their adjacent heat-affected zones in premium alloy or heat-treated cwr still tend to have different microstructure and wear characteristics than the parent rails, leading to the development of bumps or dips in service, the AAR Technical Center in Chicago has been investigating the practicality of post-welding heat treatment. A 15-rail string welded in its experimental barrel furnace at the Selas Corp. of America plant in Dresher, Pa., is entering field test on a curve in

Cajon Pass where 60 MGT of Santa Fe and UP traffic will rapidly check out its uniformity and wear rate.

Rail heat treatment during this first developmental phase has been done in two separate passes through the furnace, hardening with a polymer alcohol/water spray (similar in cooling rate to an oil quench) followed by a five- to six-minute tempering at 1,175 degrees Fahrenheit resulting in surface hardness of 340 to 360 Brinell. Experience with the rig has defined improvements to be incorporated in a second-phase pilot-production model. To be located near some participating railroad's welding plant (currently unselected, with more than one road expressing interest in playing the host), it will be designed to quench and temper in one pass.

Reasons behind increasing enthusiasm on the part of project leader Dan Stone and other railroad and AAR rail researchers for the barrel furnace's potential are several:

—Not only is weld-area microstructure improved but the reheat temperature, only 200 to 300 degrees below the final rolling temperature in the rail mill, results in grain refinement and better toughness throughout than that in new controlled-cooled rail.

—Running relay cwr through the barrel-furnace cycle can remove its accumulated fatigue history, in effect restoring its youth and shifting wear/fatigue life relationships back toward those typical of the era of lower axle loads.

—Practical logistic precedures for returning, selecting and reassembling cwr into high-quality strings for relay have been demonstrated to exist, as at Southern's Atlanta plant.

• **The corrugation question.** Another persistent rail problem, with implications for the rest of the track structure as well, is its tendency to develop corrugations. The remedy for these undulations in the rail surface is available and in service in the form of the familiar contractor-operated or railroad-owned cars or trains with controls of ever-increasing finesse and a a cost of a few hundred dollars per pass-mile. These machines use anywhere from 16 to 120 stones to grind away enough metal to restore the rail surface.

The good news is that a study by A.M. Zarembski, former track research manager for the AAR and now Speno Rail Services director of R&D, indicates that every dollar put into grinding rail before the corrugations have reached a depth (about 0.05 inch) where impact loads are significantly increased saves at least eight dollars in rail life, tie, ballast and track surfacing costs. And others knowledgeable in the field but without his reason for bias believe that his predictions are conservatively based and probably understate the benefit ratio.

Also on the good-news side is the idea, brought into practicality by the availability of such voracious grinding rigs and being used or tested in Australia, Canada and elsewhere, of creating *asymmetrical railhead contours* so that wheel tread conicity may be effective in rolling wheels around mild (up to two- or three-degree) curves with significantly less flange contact and rail wear under heavy-haul conditions.

The bad news is that so far no theory explaining the mechanics of rail corrugation has proven valid in a wide enough set of circumstances to lead the way to preventing it in the first place. A major corrugation experiment completed at FAST has provided a body of well-recorded data which will remain valid for use in further studies of the problem and offers some guidelines which may be helpful in not-too-different conditions elsewhere, though the results themselves provided mostly surprises. At FAST, rails above a certain hardness generally didn't corrugate; but a recent British Rail paper on the subject mentions that they find that harder rail corrugates more than soft.

All things considered, today's steel rail remains one of the best-understood and, for the punishment it receives, most reliable of engineering artifacts—but that doesn't mean it is about to run out of "opportunities" for research. ■

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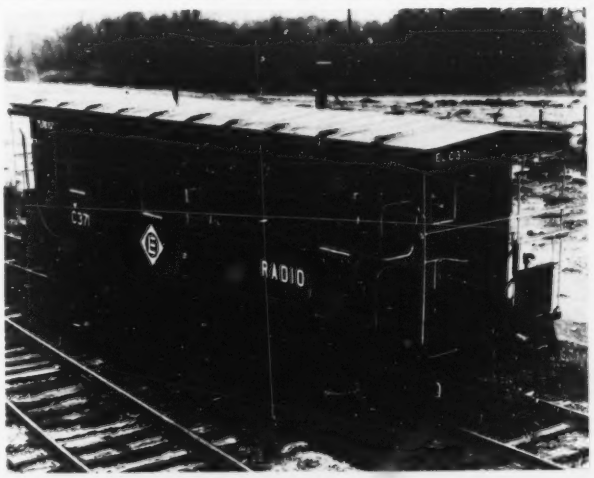

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